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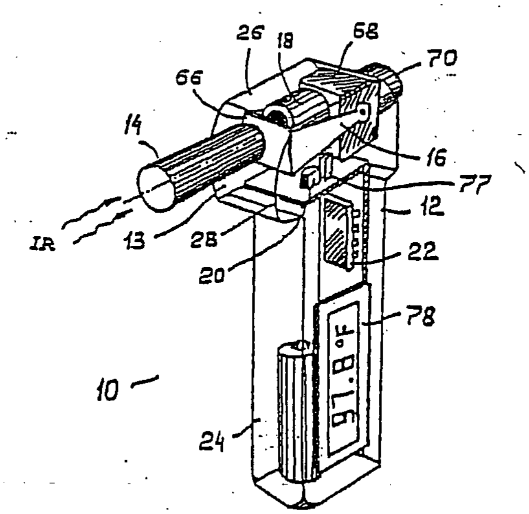
(54) Title: INFRARED ELECTRONIC THERMOMETER AND METHOD FOR MEASURING TEMPERATURE

(57) Abstract

An electronic infrared thermometer comprising a housing (12) forming an interior chamber (13), a pyroelectric sensor (18) mounted within the chamber for sensing temperature change and generating an indicative electrical signal, means (14) for directing infrared radiation (IR) from the object (11) to be measured to the pyroelectric sensor (18), a shutter assembly (16) for controlling the passing of infrared radiation (IR) to the pyroelectric sensor (18), an ambient temperature sensor (20) for sensing ambient temperature within the interior chamber (13) and generating an electrical signal indicative thereof, an electrical circuit (22) for processing the electrical signals to calculate the temperature of the object (11) to be measured, and an indicator (78) for indicating the calculated temperature. The process for measuring the temperature of an object (11) is also disclosed comprising shielding the pyroelectric sensor (18) from infrared radiation from exterior to the thermometer housing (12), selectively exposing the pyroelectric sensor (18) to infrared radiation (IR) substantially solely from the object (11) to be measured to generate a first electrical signal related to the absolute temperature of the object (11) to be measured, sensing the ambient temperature of the



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INFRARED ELECTRONIC THERMOMETER AND METHOD FOR MEASURING TEMPERATURE

Background And Summary Of The Invention

This invention relates to an electronic thermometer and more particularly to a noncontacting infrared electronic thermometer and method for measuring the temperature of an object.

The temperature of an object, such as the human body, can be determined by using a contact thermosensor or by measuring the naturally radiated energy from the body such as the radiated energy in the far infrared range. The infrared radiation is directly related to temperature of the object and can be utilized to determine the temperature of the body.

It is an object of the present invention to provide a new and improved noncontacting electronic thermometer which is accurate, reliable and economical to manufacture.

Another object of the invention is to provide a noncontacting electronic thermometer for measuring the temperature of an object virtually instantaneously.

A further object of the invention is to provide a noncontacting electronic thermometer for medical use which is compact, inexpensive and convenient and easy to use.

A further object of the invention is to provide a heat detector for medical use which detects warm spots on the surface of the skin.

A still further object of the invention is to provide a method for measuring the temperature of a body utilizing a high-speed pyroelectric infrared

sensor and a relatively slow speed ambient temperature sensor.

Brief Description Of The Drawings

Figure 1 is a diagrammatical broken away perspective view of the electronic thermometer of the present invention.

Figure 2 is a diagrammatical schematic view of the electronic thermometer of the present invention.

Figure 3 is a diagrammatical longitudinal sectional view of the pyroelectric sensor.

Figure 4 is a diagrammatical sectional view of the pyroelectric film material of the pyroelectric sensor of Fig. 3.

Figure 5 is a diagrammatical longitudinal sectional view of another embodiment of a pyroelectric sensor.

Figure 6 is a diagrammatical sectional view of the beam aiming element of Fig. 2.

Figure 7 is an electrical schematic diagram of the amplifier circuit of Fig. 2.

Figure 8 is a real time graphical representation of the operational sensor signal.

Figure 9 is a diagrammatical schematic view of a calibration assembly for the electronic thermometer.

Figure 10 is a graphic view of the wave forms produced in the calibration assembly of Fig. 9.

Figure 11 is another embodiment of the electrode configuration of the pyroelectric sensor of Fig. 9.

Figure 12 is a further embodiment of the electrode configuration of the pyroelectric sensor of Fig. 9.

Figure 13 is a diagrammatical schematic view of an alternate calibration assembly.

Figure 14 is a diagrammatical perspective view of a heat detector.

Figure 15 is a diagrammatical schematic view of the heat detector of Figure 14.

Figure 16 is a diagrammatical longitudinal sectional view of an additional embodiment of a pyroelectric sensor.

Figure 17 is a diagrammatical longitudinal sectional view of a further embodiment of a pyroelectric sensor.

Description Of The Preferred Embodiments

Referring to the drawings wherein like numerals are used to identify the same or like parts, the electronic thermometer of the present invention is generally designated by the numeral 10. Referring to Figures 1 and 2, thermometer 10 generally comprises a housing 12 forming an interior chamber 13, a barrel or wave guide 14 for directing infrared radiation into the chamber 13, a shutter assembly 16 for controlling the passage of infrared radiation through the barrel 14, a pyroelectric sensor assembly 18, an ambient temperature sensor 20, and an electronic circuit 22.

The housing 12 has an elongated lower end 24 which forms a pistol grip type handle of convenient size for one hand operation. The upper end 26 of the housing 12 forms the interior chamber 13 for mounting the pyroelectric sensor assembly 18 and the ambient temperature sensor 20, and provides a shield to exterior infrared radiation other than that received through the barrel 14.

The barrel 14 is mounted to the forward side 28 of housing 12 in alignment with the pyroelectric sensor 18 so as to direct or aim infrared radiation from the object 11 to be measured to the pyroelectric sensor mounted within the chamber 13. The barrel 14 is preferably made of metal and is interconnected to the pyroelectric sensor 18 so as to be in thermal equilibrium therewith. Alternately, the interior of the barrel may be metallized.

Referring to Fig. 6, the barrel 14 is cylindrically shaped with a smooth, shiny interior surface 30 to facilitate transmission of infrared radiation from the open receiving end 32 to the pyroelectric sensor 18 and to provide a low emissivity to reduce error generated by secondary radiation from the barrel 14 in the event the barrel temperature differs somewhat from the temperature of the pyroelectric sensor 18. The overall length of barrel 14 determines the angle of view A as shown in Fig. 6 and for most medical applications, the length of the barrel is preferably in the range of 2-10 centimeters.

Preferably, the outer surface 34 of the barrel 14 is thermally isolated from ambient heat sources such as the human body by a protective thermoisolator coating 36. An acceptable thermoisolator coating is plastic, e.g., a plastic made from a phenolic resin. The exterior surface of the protective coating 36 is shiny to reflect outside heat. As shown in phantom line in Figure 6, a removable disposable protective cover 38 may be utilized in certain applications to prevent the barrel surface from contacting the object to be measured, e.g., to prevent contamination. The cover 38 has a low thermoconductivity and an acceptable material is a polyethylene type material. Alternately, a suitable optical assembly such as one comprising a polyethylene Fresnel lens may be utilized in place of the barrel 14 to direct the infrared radiation from the object 11 to the pyroelectric sensor 18.

The pyroelectric sensor assembly 18 is mounted within the chamber 13 and, as shown in Figure 2, is positioned in alignment with the barrel 14 so as to receive the infrared radiation passing through the barrel 14. Referring to Figure 3, the pyroelectric sensor assembly 18 comprises a base 40 forming an open-ended interior recess 42 for mounting a

pyroelectric film 44 to receive the infrared radiation from the barrel 14. The pyroelectric film 44 is clamped between an outwardly disposed peripheral clamp 46 and an inwardly disposed peripheral contact ring 48. The contact ring 48 is securely mounted within the recess 42 in spaced disposition to the base 40. An insulating insert spacer 50 electrically insulates the contact ring 48 from the base 40 and, as shown in Fig. 3, the insert 50 cooperatively engages the interior end of the contact ring 48 so as to maintain the contact ring in spaced disposition relative to the base 40.

In the illustrated embodiment, the pyroelectric film is an ultra thin foil of pyroelectric material such as polyvinylidene fluoride (PVDF). If electrically polarized, such a film exhibits a pyroelectric effect in that it is able to generate an electrical charge in response to a change of its temperature produced by the receipt of infrared radiation. Other configurations and materials such as those generally disclosed in Smith et al, U.S. Patent 4,379,971 and Cohen et al, U.S. Patent 3,809,920 (which disclosures are incorporated herein by reference) may also be utilized. In the illustrated embodiment, polyvinylidene fluoride is a preferable material since it is sensitive to minute and rapid temperature changes in response to the infrared radiation utilized herein and is relatively economical.

Referring to Fig. 4, the pyroelectric film 44 may be of varying thicknesses ranging from 5 to 100 microns with the thickness being determined by the sensitivity and speed response desired for a particular application. A pair of planar electrodes 52, 54 are fixed on opposite sides of the pyroelectric film 44 with the electrode 52 facing outwardly from the recess 42 to first receive the infrared radiation from the barrel 14. In the illustrated embodiment, the outer

electrode 52 is black to provide high emissivity and absorption of infrared radiation and the inner electrode 54 is nontransparent and highly reflective of infrared radiation. Alternately, the outer electrode 52 may be transparent to far infrared radiation and the inner electrode 54 may be reflective to provide a greater speed response and sensitivity.

In assembly, the base 40 and the clamp 46 are electrically connected to provide shielding for the pyroelectric film 44. The base 40 and the outer electrode 52 are connected to ground by the ground lead 56. The inner electrode 54 is electrically connected to the lead wire 58 through the contact ring 48. The lead wires 56, 58 connect the pyroelectric sensor assembly 18 to the electronic circuit 22. The pyroelectric film 44 is polarized during the manufacturing process so that the polarity of the signal generated in response to the reception of infrared radiation is compatible with the electronic circuitry being utilized. In the illustrated embodiment, the pyroelectric film is appropriately polarized so that the inner electrode generates a negative signal in response to a positive temperature change. In operation, the pyroelectric sensor 18 senses temperature change and generates an electrical signal indicative thereof.

In practice, it has been found that pyroelectric sensor assemblies 18 employing pre-polarized pyroelectric films 44 are substantial superior in terms of cost and ease of manufacture to prior art infrared sensors employing, for example, charged polymer films, thermocouples, thermopiles, or the like. Specifically, in comparison to the prior art sensors, film 44 has a relatively large area, e.g., on the order of 1 cm^2, and is sensitive to infrared radiation impinging on essentially any part of that area. Accordingly, the

infrared thermometers of the present invention do not require systems for focusing infrared radiation on the sensor, such as, focusing tubes, parabolic mirrors, lenses, or the like. This makes for a significantly simpler device, which in turn, lowers the overall cost of the device and makes the device easier to manufacture.

The ambient temperature sensor 20 is mounted within the interior chamber 13 in thermal equilibrium with the pyroelectric sensor 18, the barrel 14, and the shutter element 66 so as to sense or monitor the internal temperature of the housing 12. The ambient temperature sensor 20 senses the internal temperature of the housing 12 and generates an electrical signal proportional thereto which is applied to the electronic circuit 22 through the connector 64. Acceptable temperature transducers that may be utilized for such ambient temperature sensing include thermistors, thermopiles, semiconductors, etc. Importantly, the ambient temperature sensor may be relatively slow-acting as contrasted to the fast-acting pyroelectric sensor and need only have a response time sufficient to track the changes of the internal ambient temperature of the chamber 13.

The exposure of the pyroelectric film 44 to infrared radiation directed through the barrel 14 is controlled by the shutter assembly 16. The shutter assembly 16 comprises a shutter 66, a shutter control mechanism 68, and a manually actuated pushbutton 70. The shutter 66 is operationally mounted at the inner end 33 of the barrel 14 so as to be actuable between a normally closed position closing off the transmission of infrared energy from the barrel 14 to the pyroelectric sensor 18 and an open position permitting infrared energy to pass from the barrel 14 to the pyroelectric sensor 18.

The shutter control mechanism 68 is of conventional design providing a high shutter opening speed in the range of 5-25 milliseconds. Acceptable conventional mechanisms include a mechanical trigger assembly, a solenoid actuated means, a stepper motor assembly, etc. The shutter 66 is actuated to an open position by depression of the pushbutton 70 and remains in the open position a sufficient time to permit the pyroelectric sensor 18 to generate the electrical signal responsive to shutter opening as explained hereinafter. The shutter 66 is returned to its normally closed position after approximately 200 milliseconds. A mechanical timing gear is utilized to control the duration of the shutter 66 in the open position. Alternately, the timing gear may be electro-mechanical.

The shutter control mechanism 68 includes noise supression elements and shock absorbers to reduce acoustical noise and other mechanical-forces during the shutter opening operation to control the accuracy of the responsive electrical signal generated by the pyroelectric sensor 18. Since the pyroelectric film 44 has piezoelectric properties, excessive acoustical noise or mechanical force can produce detrimental error and noise in the electrical signal generated by the pyroelectric film 44 in response to temperature changes.

The shutter 66 is configured to have a low thermal conductivity from its outer surface 72 to its inner surface 74 in order to prevent the shutter from becoming an extrinsically dependent secondary source of radiation to the pyroelectric film 44. Both the inner and outer surfaces of shutter 66 are reflective in nature in order to reduce emissivity and heating from external sources. The shutter 66 is also mounted

within the chamber 13 so as to be in thermal equilibrium with the pyroelectric sensor 18.

The electronic circuit 22 includes an amplifier circuit 60, a microprocessor or microcontroller 76, a shutter sensor switch 77 and a digital visual display device 78. The microprocessor 76 is interconnected to the ambient temperature sensor 20, the amplifier circuit 60 and the shutter sensor switch 77 to receive electrical input signals indicative of the internal ambient temperature of the thermometer housing 12, the actuation of shutter assembly 16, and the temperature differential between the pyroelectric sensor 18 and the object to be measured. The microprocessor 76 is of conventional design having suitable data and program memory and being programmed to process the electrical signal from the ambient temperature sensor 20 and the amplified electrical signal from the pyroelectric sensor 18 in accordance with the following description to calculate the absolute temperature of the body 11 to be measured. Based upon the calculated temperature of the subject 11, the microprocessor 76 generates a control signal to drive the display device 78 to visually indicate the calculated temperature.

More specifically, the amplitude of the electrical signal generated by the pyroelectric sensor is a nonlinear function of the difference between the temperature of the subject to be measured and the temperature of the sensor prior to exposure to the radiation emitted by the subject, i.e., the difference between the temperature of the subject and the ambient temperature of the thermometer. The general characteristics of this function can be described in terms of the Stefan-Boltzman equation for radiation and the Fourier equation for heat transfer. Both these equations, however, are highly non-linear. Moreover, there exists no known analytical relationship between

the amount of radiation striking a pyroelectric film, such as a PVDF film, and the voltage produced by the film.

In accordance with the present invention, it has now been found that notwithstanding these non-linearities and the lack of an analytical relationship for film output, the temperature of a subject can be accurately determined using pyroelectric films by means of the following procedure. First, the voltage V_{ir} produced by the film in response to radiation from the subject is approximated by the formula:

$$V_{ir} = f(T_a)(T_s^4 - T_a^4) \quad (1)$$

where T_s is the absolute temperature of the subject, T_a is the absolute ambient temperature determined from ambient temperature sensor 20, and $f(T_a)$ is a polynomial in T_a, namely,

$$f(T_a) = a_0 + a_1T_a + a_2T_a^2 + a_3T_a^3 + \ldots$$

Next, the coefficients a_0, a_1, a_2, a_3, etc. are determined for the particular sensor design and type of film being used by measuring V_{ir} for a series of known T_s's and T_a's, substituting those values into equation 1, and solving the resulting set of simultaneous equations for the polynomial coefficients. In practice, it has been found that for measuring body temperatures, sufficient accuracy can be achieved through the use of only three terms, i.e., through the use of a second order polynomial in T_a. For other applications, where greater accuracy may be required, more terms can be used if desired.

Finally, the temperature of a subject whose temperature is to be measured is determined by microprocessor 76 by evaluating the following equation using V_{ir} from pyroelectric sensor 18, T_a as derived from ambient sensor 20, and the polynomial coefficients a_0, a_1, a_2, a_3, etc. determined as described above:

$$T_s = (V_{ir}/f(T_a) + T_a^4)^{1/4}$$

The microprocessor 76 is thus adapted to provide the necessary analysis of the electrical signals from the ambient temperature sensor and the pyroelectric sensor, including appropriate scaling, correction, etc., to calculate absolute temperature. The calculated temperature is processed into a digital format for storage in memory and for generating a control signal to drive the digital display. In practice, using the above procedure and a PVDF film, it has been found that body temperatures can be reliable measured with the thermometer of the present invention to within approximately 0.1°C.

Referring to Figure 8, a graphic representation of V_{ir} is shown for an exemplary temperature measurement of an object having a temperature greater than the internal ambient temperature of the thermometer. As indicated, the pyroelectric sensor signal (V_{ir}) quickly reaches its maximum or peak value after the opening of the shutter and starts to slowly decay. The rate of decay of the signal is dependent upon various physical parameters of the pyroelectric film 44 such as thickness, emissivity, thermal time constant, etc. In the illustrated embodiment, the microprocessor 76 is responsive only to the peak absolute value of the pyroelectric sensor signal so that the actual period the shutter remains open is not critical as long as the shutter is open long enough to allow the signal to reach its peak absolute value. Where the subject being measured has a temperature greater than the ambient temperature of the thermometer, the peak absolute value of the voltage signal is a maximum voltage as shown in Figure 8, whereas the peak absolute value would be a minimum voltage if the subject had a temperature lower than the ambient temperature of the thermometer. After the microprocessor 76 determines the peak value, the

measurement is complete and the microprocessor becomes insensitive or nonresponsive to further input signals from the pyroelectric sensor.

Alternatively, the microprocessor 76 may be programmed to calculate the absolute temperature of the subject by integration of V_{ir} over a predetermined fixed time frame t_0 according to the following equation:

$$e = k_i \int_0^{t_0} V_{ir}\, dt$$

where, k_i = a calibration factor in 1/sec.

The integration method of measurement calculation is more resistant against high frequency noise such as may be picked up by the pyroelectric sensor and is particularly advantageous where the temperature of the subject to be measured is relatively close to the internal temperature of the thermometer.

It is important to note that for both the peak absolute value approach and the integration approach, the signal being measured is the transient response of the pyroelectric film to the infrared radiation reaching the film during the time when shutter 66 is open, that is, in accordance with the present invention, the transient response of the film to a single pulse of infrared radiation is all that is measured. This is in direct contrast to prior art infrared thermometers which either measured the steady state response of the sensor or employed a chopper to break up the incoming infrared radiation into a series of pulses and then averaged the response of the sensor to those pulses. By measuring the transient response, the thermometer of the present invention has a faster response time than prior art thermometers which had to wait until a steady state was achieved; by using only one pulse, the present invention avoids the need for

both a chopper and averaging circuitry, thus allowing for the production of a less complicated and less expensive device which is easier to manufacture. Moreover, notwithstanding the fact that only one pulse of infrared radiation is measured, the thermometer of the present invention has been surprisingly found to consistently and accurately measure body temperatures.

Referring to Fig. 7, the amplifier circuit 60 of the present invention is shown in detail. In the illustrated embodiment, the pyroelectric sensor 18 generates a negative signal in response to positive temperature change. The pyroelectric sensor signal is applied via lead 58 to the negative input terminal of the amplifier 61 and an internally generated reference voltage (V_{ref}) is applied to the positive input terminal. Preferably, the amplifier has a JFET or CMOS input stage and is a current-to-voltage converter whose input impedance is dependent upon the bias resistor 80 and the ratio of resistors 82, 84. Capacitor 86 provides negative feedback to maintain the stability of the amplifier and reduce high-frequency noise. Capacitor 88 blocks out low frequency drifts and offset voltages in the voltage output signal V_{out} which is applied to the input of microprocessor 76 by lead 87. The analog switch 90 is normally in a closed position prior to actuation of the shutter assembly 16 so that the amplifier output voltage is equal to the internally generated reference voltage. The analog switch 90 is connected by lead 92 to the shutter actuation sensor switch 77 which generates an indicator signal upon actuation of the shutter assembly 16 by the pushbutton 70. Upon actuation of the shutter assembly, the indicator signal generated by the sensor switch 77 causes the analog switch 90 to open and the voltage output V_{out} is then the amplified signal V_{ir} from the pyroelectric sensor 18 which changes rapidly in

response to the infrared radiation from the subject to be measured.

In operation, the outer end of the barrel 14 is positioned in spaced disposition adjacent the subject 11 to be measured. Upon actuation of the pushbutton 70 and the opening of the shutter 66, infrared radiation from the subject 11 is directed along the barrel 14 to the pyroelectric film 44 of the pyroelectric sensor 18. The pyroelectric film 44 generates an electrical signal which is a function of the change in temperature caused by the infrared radiation from the subject 11. Based upon the ambient temperature of the interior of the thermometer as sensed by the ambient sensor 20 and the temperature change of the pyroelectric sensor assembly caused by the infrared radiation reaching the sensor from the subject, the temperature of the subject is calculated by the microprocessor 76 and displayed on the digital display 78. The response time of the thermometer is relatively fast being in the order of 0.25 seconds. As can be seen from the foregoing, a fast temperature reading is obtained with a noncontacting electronic thermometer which is easy to use and economical to manufacture.

Another embodiment of a pyroelectric sensor assembly is shown in Figure 5 being generally designated by the numeral 19. The pyroelectric sensor 19 comprises a contact ring or insert 48 integrally formed with a contact pin 58 which extends through the insulating insert 50. The pyroelectric film 44 is clamped between the contact ring 48 and the clamp 46 with the clamp 46 being held in place by the rolled edges 41 of the base 40. The outer electrode 52 is connected to ground through the clamp 46 and the base 40 while the inner electrode 54 is connectable to the amplifier circuit 22 through the contact ring 48 and the contact pin 58. The remaining elements function

similarly to the embodiment of Figure 3 and need not be described in detail. The configuration of Figure 5 is particularly suited for economical high-volume manufacture and also facilitates the assembly of the thermometer 10 because of its compatibility with automated manufacturing processes.

Additional embodiments of the pyroelectric sensor assembly are shown in Figures 16-17. In Figure 16, polymer film 44, having electrodes 52 and 54 on its front and rear faces, is mounted inside nonconductive housing or support 150. The film can be mounted to the housing in various ways, such as, through the use of glue, heat welding, or the like. To protect the film, the front face of the sensor can include a cover 163 made of material which is transparent to far infra-red radiation, such as, polyethylene. To equalize the pressure on both sides of the film, housing 150 preferably includes an opening 160 in its rear wall leading into the cavity formed by the film and the walls of the housing.

Two contacts 161 and 162 are molded into housing 150. Contact 162 is connected to front electrode 52, and contact 161 is connected to rear electrode 54. These connections can be made by physical contact or via a conductive media, such as, a conductive epoxy, e.g., Rgon.

Figure 17 shows a modified version of the sensor assembly of Figure 16 wherein ambient sensor 20 is mounted in the same housing 164 as polymer film 44. In particular, ambient sensor 20 is mounted in the cavity formed by film 44 and the walls of housing 164. In this way, better thermal coupling between the film and the ambient temperature sensor is achieved.

Referring to Figure 9, an optional calibration circuit 94 is shown for calibrating the pyroelectric sensor signal to compensate for possible variations due

to material aging, temperature drifts, instability of electronic components, etc. which may produce unacceptable error in the temperature measurement. The pyroelectric film 44 has piezoelectric properties which are necessarily subjected to the same environmental factors (such as material aging, temperature, etc.) as its pyroelectric properties. Consequently, calibration may be attained by an electrical calibration, i.e., piezo-calibration, as opposed to a thermal calibration, i.e., pyro-calibration. The application of a predetermined reference signal to the piezoelectric-pyroelectric film will generate a mechanical stress or deflection at one portion of the film and that stress may be sensed in the other portion of the film since it generates a responsive signal. Thus, calibration is attained through application of a predetermined electrical calibration signal to the pyroelectric film prior to each temperature measurement calculation to generate a responsive signal. The responsive signal is utilized by the microprocessor as a correction factor in the temperature calculations.

Referring to Figure 9, the outer planar electrode 96 on the outwardly facing surface of the pyroelectric film 44 is comprised of two separate spaced electrode segments 98, 100. The electrode segment 100 is connected to amplifier circuit 60. The electrode segment 98 is connected to switch 102 which alternately interconnects the electrode segment 98 to either the amplifier circuit 60 or to an excitation signal circuit 104.

The excitation circuit 104 is of conventional design for producing a predetermined electrical calibration signal 106 adapted to excite the piezoelectric film to produce a mechanical stress and, in turn, a responsive electrical signal 108 (Figure 10). The value of the responsive electrical signal at

the time of assembly and initial calibration of the thermometer 10 will constitute a predetermined standard and is stored in memory. The switch 102 and the excitation signal circuit 104 are controlled by the microprocessor 76 and, upon command from the microprocessor 76 during the calibration operation, the excitation signal circuit generates a predetermined electrical calibration signal 106.

The calibration operation is performed with the shutter 66 in a closed position as diagrammatically shown in Figure 9. Prior to opening the shutter 66, the switch 102 interconnects the electrode segment 98 to the signal excitation circuit 104 and the predetermined electrical signal 106 is applied to the electrode 98. Due to the piezoelectric properties of the pyroelectric film 44, this causes a mechanical stress and, in turn, the mechanical stress causes the piezoelectric film 44 to generate a responsive electrical signal 108 in electrode 96 which is conducted to the amplifier circuit 60 via the electrode segment 100. Since the mechanical stress calibration signal is a predetermined value, deviation in the response signal 108 is indicative of changes in the pyroelectric sensor 18 and the degree of deviation from the predetermined standard provides the necessary calibration information for appropriate correction by the microprocessor 76. Immediately following the calibration operation, the switch 102 interconnects the electrode segment 98 to the amplifier circuit 60 which thereby doubles the infrared sensitivity area of the film and the temperature measurement operation is performed as previously described relative to the embodiment of Figs. 1 and 2.

Preferably, calibration is performed immediately prior to each measurement operation to ensure reliable and accurate absolute temperature measurement. Any

changes in the pyroelectric properties of the pyroelectric film 44 due to aging, environment, etc. will be automatically compensated for by the microprocessor 76 in calculating the absolute temperature of the subject.

Referring to Figs. 11 and 12, alternate embodiments of the planar electrode segments 98, 100 are shown. In Fig. 11, the electrode segments 98, 100 are interdigitized on the inward facing surface of the pyroelectric film 44. In Fig. 12, the electrode segment 98 is coaxial to the electrode segment 100 and the electrode segment 98 may be permanently connected to the excitation network 104 thereby eliminating the necessity for switch 102. However, the thermal sensitive area of the pyroelectric film 44 will be limited to the electrode segment 100.

Referring to Fig. 13, an alternate configuration for calibrating the pyroelectric sensor assembly 18 is shown. In this configuration, a heating element 108 is controlled by a controller 110 to provide a predetermined stable infrared radiation level upon command from the microprocessor 76.

The inner surface of the shutter 66 has a reflective plate 114 aligned with the heating element 108 and the pyroelectric sensor 18 so as to reflect the infrared beam 112 from the heating element 108 to the pyroelectric sensor assembly. Necessarily, the generated infrared radiation beam 112 is stable under operating conditions. The electrical signal generated by the pyroelectric sensor in response to the infrared beam 112 provides a reference signal to the microprocessor 76 to enable it to calculate the amount of correction required in the subsequent temperature measurement calculation. Again, the calibration operation is performed with the shutter 66 in a closed position and preferably the calibration operation is

performed prior to each temperature measurement operation.

Alternately, the microprocessor 76 may be provided with a predetermined table of error correction data based upon the known sources of error and changes in the responsive characteristics of the pyroelectric film. The microprocessor is programmed to adjust the calculated absolute temperature in accordance with the error correction data.

As can be seen, a new and improved noncontacting electronic thermometer has been provided which is accurate, reliable, and economical to manufacture. In operation, the electronic thermometer is compact and easy to use and measures absolute temperature of an object virtually instantaneously.

Referring to Figures 14 and 15, a further embodiment of the present invention is shown in the nature of a heat differential detector 130 for the detection of warm spots on a surface. The detection of warm spots is often desirable to locate bone fractures, tissue inflammation, etc. The heat detector 130 generally comprises a housing, a barrel 14, a pyroelectric sensor assembly 18 having a pyroelectric film 44, an electric circuit 22 and an indicator light 116.

The barrel 14 and pyroelectric sensor 18 function as previously described with respect to the embodiment of Figure 1. The electronic circuit 22 generally comprises an amplifier 60, a comparator 118, and an indicator circuit 120. The output of the amplifier 60 is connected through capacitor 122 to the comparator 118. The threshold point of the comparator may be varied by the potentiometer 124. A pushbutton reset switch 126 permits discharge of the capacitor 122 to ground. The indicator circuit 120 is connected to the comparator 118 and drives the indicator light 116 or

any other acceptable indicator such as an audio tone generator, etc.

In operation, the capacitor 122 is discharged by momentary actuation of the switch 126 prior to beginning the sensing operation. To sense or detect a warm spot, as for example the warm spot 128 on skin surface 131 as shown in Figure 14, the heat detector is positioned so that the open receiving end 32 of the barrel 14 is adjacent the surface 131. The heat detector 130 is then moved along the surface at approximately a constant rate of speed. When the warm spot 128 enters the field of view of the barrel 14, the increase in infrared radiation from the warm spot 128 causes the pyroelectric sensor 18 to generate an indicative electrical signal. The amplified electrical signal is applied to the comparator 118 and if the electrical signal exceeds the set threshold value of the comparator, the indicator circuit 120 will be actuated to drive the indicator light 116. The threshold point of the comparator my be varied depending on the particular heat sensing application.

Accordingly, a heat detector is provided which is convenient and easy to use and which is economical to manufacture.

As will be apparent to persons skilled in the art, various modifications and adaptions of the structure above-described will become readily apparent without departure from the spirit and scope of the invention, the scope of which is defined in the appended claims.

What Is Claimed Is:

1. An electronic thermometer comprising:

a housing forming an interior chamber,

a pyroelectric sensor means for sensing temperature change and generating a first electrical signal indicative thereof, said pyroelectric sensor means being mounted within said interior chamber,

means for directing infrared radiation from the object to be measured to the pyroelectric sensor means, said directing means being mounted to said housing in operational alignment with said pyroelectric sensor means,

shutter means for controlling the passing of infrared radiation from said directing means to said pyroelectric sensor means,

temperature sensor means for sensing ambient temperature and generating a second electrical signal indicative thereof, said temperature sensor means being mounted within said chamber so as to sense the temperature of said pyroelectric sensor means,

electrical circuit means for processing the first electrical signal generated by said pyroelectric sensor means indicative of temperature change and the second electrical signal generated by said temperature sensor means to calculate the temperature of the object to be measured, said circuit means being interconnected to said pyroelectric sensor means and said temperature sensor means, and

indicator means for indicating the calculated temperature, said indicator means being connected to said circuit means.

2. The device of claim 1 wherein said pyroelectric sensor means includes a film of pyroelectric material.

3. The device of claim 2 wherein said pyroelectric material is polyvinylidene fluoride.

4. The device of claim 2 wherein said film is mounted on a support which includes means for equalizing the pressure on either side of the film.

5. The device of claim 4 wherein said support and said film form a cavity and said means for equalizing the pressure on either side of the film comprises an aperture passing through a wall of the support into the cavity.

6. The device of claim 5 wherein the temperature sensor means is mounted in the cavity.

7. The device of claim 1 wherein said pyroelectric sensor means comprises

a film of pyroelectric material having oppositely disposed forward and rearward surfaces,

a first electrode on said forward surface adapted to provide high absorption of infrared radiation,

a second electrode on said rearward surface being nontransparent and highly reflective of infrared radiation, and

means for mounting said film within said interior chamber so that said forward surface is aligned to receive the infrared radiation from said directing means.

8. The device of claim 1 wherein said pyroelectric sensor means comprises

a film of pyroelectric material having oppositely disposed forward and rearward surfaces,

a first electrode on said forward surface being transparent to infrared radiation,

a second electrode on said rearward surface being reflective of infrared radiation, and

means for mounting said film within said interior chamber so that said forward surface is aligned to receive the infrared radiation from said directing means.

9. The device of claim 1 wherein:

said shutter means is actuable from a closed position preventing the passage of infrared radiation from said directing means to said pyroelectric sensor means to an open position permitting the passage of infrared radiation from said directing means to said pyroelectric sensor means, and

said electrical circuit means comprises means for sensing the actuation of said shutter means from a closed position to an open position.

10. The device of claim 1 which comprises means for calibrating the electrical signal generated by said pyroelectric sensor means.

11. The device of claim 10 wherein

said pyroelectric sensor means comprises a pyroelectric film having oppositely disposed forward and rearward surfaces, said forward surface being aligned to receive infrared radiation from said directing means, and

said calibrating means comprises:

first and second electrode segments mounted in spaced disposition on said forward surface of said pyroelectric film,

means for generating a predetermined mechanical stress calibration signal adapted to excite said pyroelectric film to generate a responsive calibration signal, said generating means being interconnected to said first electrode segment, and

means for adjusting said first electrical signal of said pyroelectric sensor means based upon the deviation of said responsive calibration signal from a predetermined standard, said circuit means being interconnected to said second electrode segment.

12. The device of claim 11 wherein said first electrode segment is coaxial to said second electrode segment.

13. The device of claim 11 wherein said first and second electrode segments are interdigitized on the forward surface of the pyroelectric film.

14. The device of claim 10 wherein said calibrating means comprises

means for generating a predetermined level of infrared radiation adapted to excite said pyroelectric sensor means to generate a responsive calibration signal, said generating means being mounted in operative alignment with said pyroelectric sensor means so as to direct the generated infrared radiation to said pyroelectric sensor means, and

means for adjusting said first electrical signal of said pyroelectric sensor means based upon the deviation of said responsive calibration signal from a predetermined standard, said circuit means being interconnected to said pyroelectric sensor means.

15. The device of claim 1 wherein said shutter means comprises:

a normally closed shutter element moveably mounted within said interior chamber for actuation between open and closed positions, said shutter element being interposed between said directing means and said pyroelectric sensor means so as to prevent the passage of infrared radiation from said directing means to said pyroelectric sensor means in said closed position and to permit the passage of infrared radiation from said directing means to said pyroelectric sensor means in said open position, and

means for controllably actuating said shutter element from said normally closed position to said open position.

16. The device of claim 15 wherein said shutter element comprises first and second oppositely-disposed surfaces with said shutter element being mounted within said interior chamber so the said first surface faces

said directing means and said second surface faces said pyroelectric sensor means when said shutter element is in said normally closed position, said shutter element being configured to have a low thermal conductivity from said first surface to said second surface with said first and second surfaces being reflective.

17. The device of claim 1 wherein said directing means comprises an elongated cylindrical wave guide of predetermined length having an outer end to receive infrared radiation from the object to be measured and an inner end in operative alignment with said pyroelectric sensor means, said wave guide being mounted to said housing and interconnected to said pyroelectric sensor means so as to be in thermal equilibrium therewith, said guide having a smooth and shiny interior surface and an outer surface, and means on said outer surface for thermally isolating said outer surface from external ambient heat sources.

18. The device of claim 17 wherein said means for thermally isolating comprises a thermoisolator coating on said outer surface.

19. The device of Claim 1 wherein the temperature of the object to be measured is calculated using the equation:

$$T_s = (V_{ir}/f(T_a) + T_a^4)^{1/4}$$

where T_s is the absolute temperature of the object to be measured, V_{ir} is the first electrical signal generated by the pyroelectric sensor means, T_a is the absolute ambient temperature determined by the electrical circuit means from the second electrical signal generated by the temperature sensor means, and $f(T_a)$ is a polynomial in T_a given by the equation:

$$f(T_a) = a_0 + a_1T_a + a_2T_a^2 + a_3T_a^3 + \ldots$$

where the polynomial coefficients a_0, a_1, a_2, a_3... are determined by exposing the pyroelectric sensor means at

a known ambient temperature to objects having know temperatures.

20. The device of Claim 19 wherein the polynomial $f(T_a)$ is a second order polynomial in T_a given by the equation:

$$f(T_a) = a_0 + a_1T_a + a_2T_a^2.$$

21. A process for measuring the temperature of an object with a thermometer having a housing providing an interior chamber and an ambient temperature sensor and a pyroelectric infrared sensor mounted within the chamber comprising the steps of:

shielding the pyroelectric sensor from infrared radiation from exterior to the thermometer housing,

selectively exposing the pyroelectric sensor to infrared radiation substantially solely from the object to be measured to generate a first electrical signal which is a function of the temperature of the object to be measured and the ambient temperature of the pyroelectric sensor immediately prior to said selective exposing,

sensing the ambient temperature of the pyroelectric sensor and generating a second electrical signal proportional thereto, and

electrically processing said first and second electrical signals to calculate the temperature of the object to be measured.

22. The method of claim 21 which comprises calibrating the sensitivity of the pyroelectric sensor prior to selectively exposing the pyroelectric sensor to infrared radiation from the object to be measured.

23. The method of claim 22 wherein the pyroelectric sensor is adapted to exhibit piezoelectric properties and calibrating the sensitivity of the pyroelectric sensor comprises:

applying a predetermined calibration signal to the pyroelectric sensor so as to cause the pyroelectric

sensor to generate a responsive electrical calibration signal and

correcting said first electrical signal generated by the pyroelectric sensor based upon said responsive electrical calibration signal and a predetermined standard value.

24. The method of claim 22 wherein calibrating the sensitivity of the pyroelectric sensor comprises

applying a predetermined level of infrared radiation to the pyroelectric sensor so as to cause the pyroelectric sensor to generate a responsive electrical calibration signal, and

correcting said first electrical signal generated by the pyroelectric sensor based upon said responsive electrical calibration signal and a predetermined standard value.

25. The method of Claim 21 wherein the temperature of the object to be measured is calculated using the equation:

$$T_s = (V_{ir}/f(T_a) + T_a^4)^{\frac{1}{4}}$$

where T_s is the absolute temperature of the object to be measured, V_{ir} is the first electrical signal generated by the pyroelectric sensor, T_a is the absolute ambient temperature determined from the second electrical signal, and $f(T_a)$ is a polynomial in T_a given by the equation:

$$f(T_a) = a_0 + a_1T_a + a_2T_a^2 + a_3T_a^3 + \ldots$$

where the polynomial coefficients a_0, a_1, a_2, $a_3 \ldots$ are determined by exposing the pyroelectric sensor at a known ambient temperature to objects having know temperatures.

26. The device of Claim 25 wherein the polynomial $f(T_a)$ is a second order polynomial in T_a given by the equation:

$$f(T_a) = a_0 + a_1T_a + a_2T_a^2$$

27. The method of claim 21 wherein exposing the pyroelectric sensor to generate a first electrical signal includes generating a first electrical signal having a peak value related to the absolute temperature of the object to be measured.

28. The method of claim 21 wherein exposing the pyroelectric sensor to generate a first electrical signal includes generating a first electrical signal having an integrated value over a predetermined time period related to the absolute temperature of the object to be measured.

29. The method of claim 21 comprising maintaining the pyroelectric sensor in approximately thermal equilibrium with said ambient temperature sensor for a predetermined time period prior to said exposing with the ambient temperature sensor being a slow responding sensor relative to said pyroelectric sensor.

30. The method of claim 21 which comprises generating a third electrical signal related to the absolute temperature of the object to be measured and driving an indicator device with said third electrical signal to indicate temperature.

31. The method of claim 21 which comprises momentarily selectively exposing the pyroelectric sensor to infrared radiation by a selectively operable shutter means.

32. The method of claim 21 wherein selectively exposing the pyroelectric sensor includes directing substantially solely the infrared radiation from the object to be measured to the pyroelectric sensor.

33. A heat differential detector comprising:

a housing forming an interior chamber,

means for directing infrared radiation from the surface of an object to the interior chamber, said directing means being mounted to said housing,

a pyroelectric sensor means for sensing temperature change and generating an electrical signal indicative thereof, said sensor means comprising:

a film of pyroelectric material having oppositely disposed forward and rearward surfaces,

a first electrode mounted on said forward surface and a second electrode mounted on said rearward surface, and

means for mounting said film within said interior chamber so the said forward surface is aligned to receive the infrared radiation from said directing means,

electrical circuit means for comparing the electrical signal generated by said pyroelectric sensor means to a preselected value and generating an indicator control signal to drive an indicator means when the electrical signal generated by said pyroelectric sensor means exceeds said preselected value, and

indicator means for indicating that the electrical signal generated by said pyroelectric sensor means exceeds said preselected value, said indicator means being connected to said electrical circuit means.

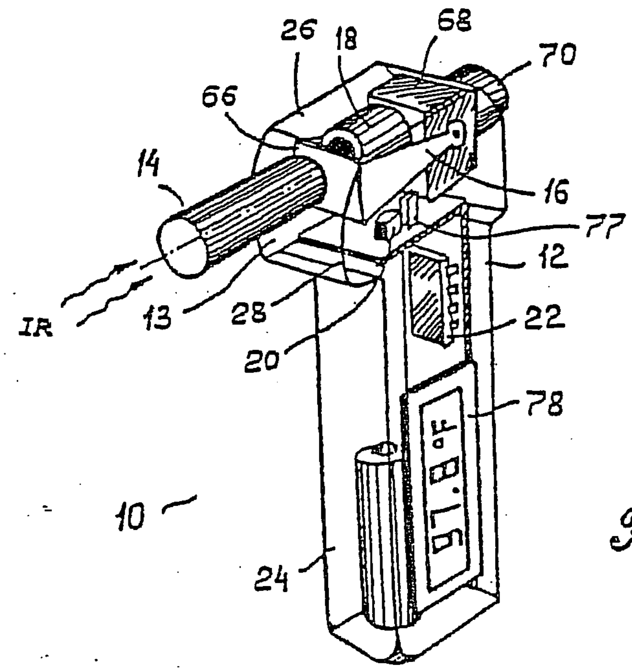
26
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Fig. 1

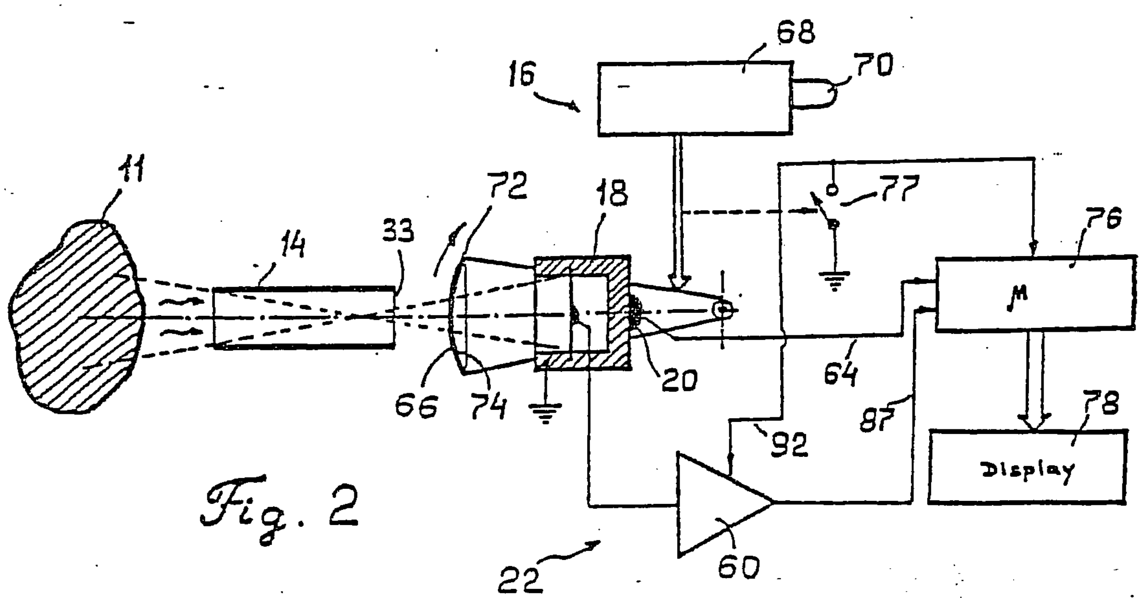
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Fig. 2

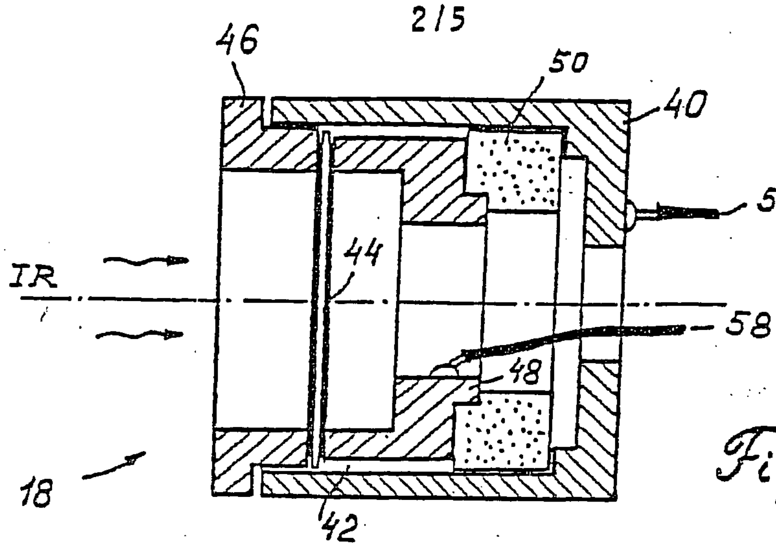


Fig. 3

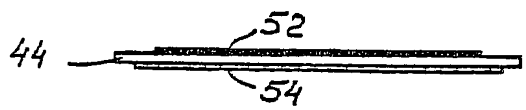


Fig. 4

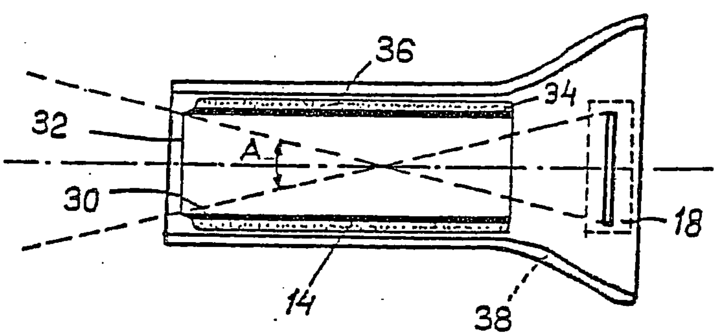


Fig. 6

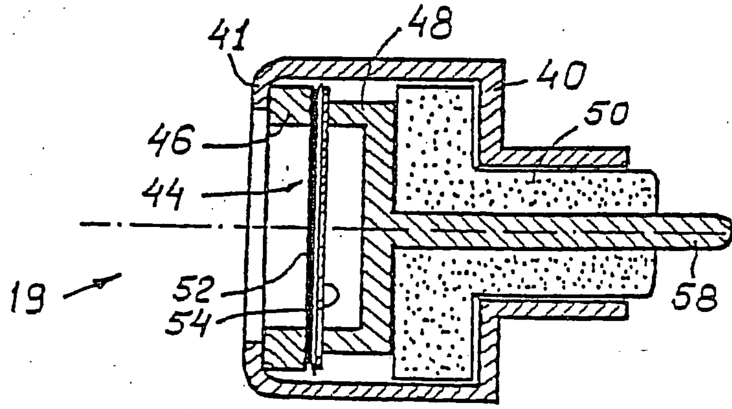


Fig. 5

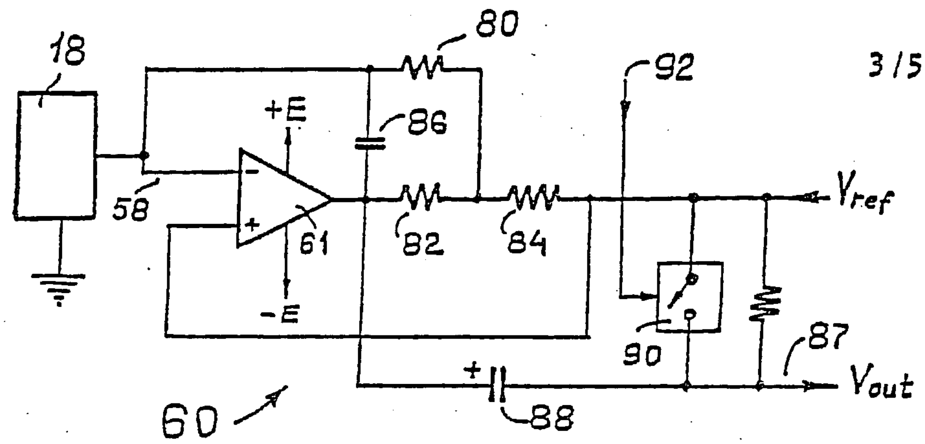


Fig. 7

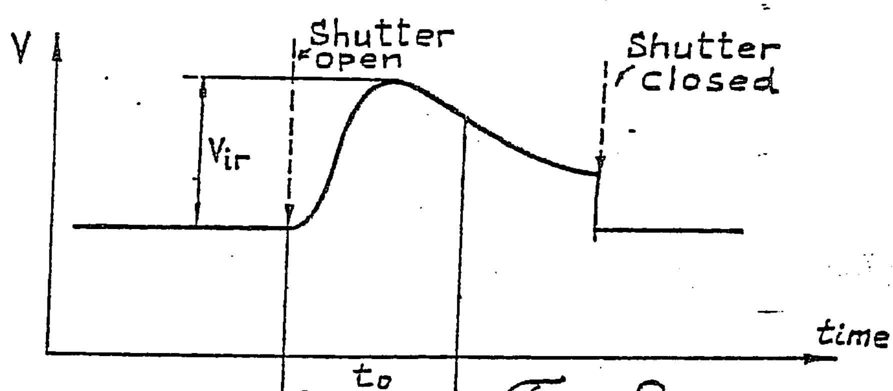


Fig. 8

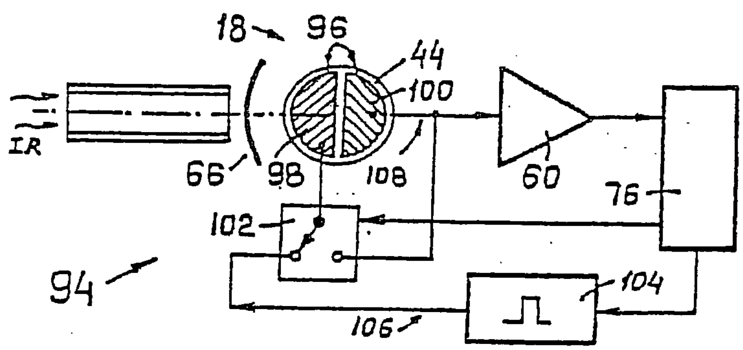


Fig. 9

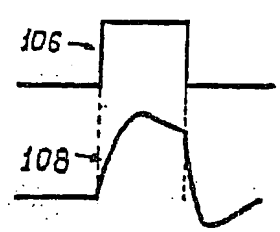


Fig. 10

Fig. 11

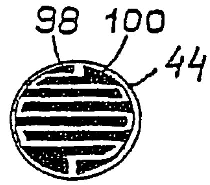
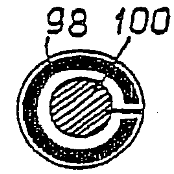


Fig. 12



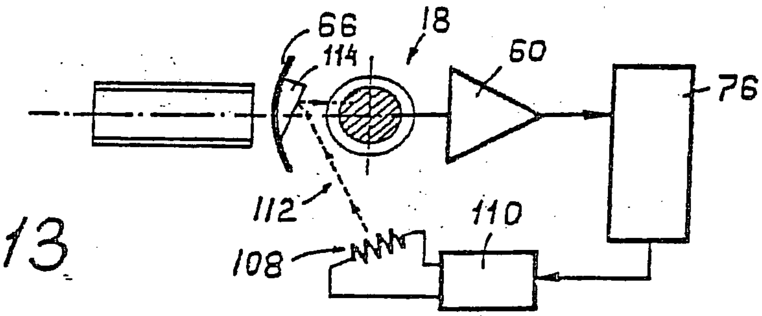


Fig. 13

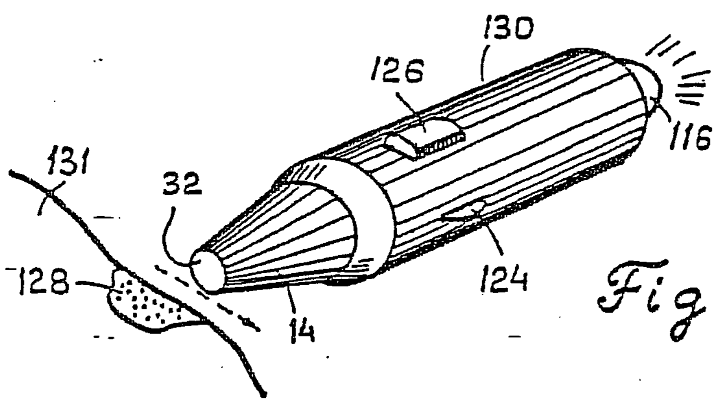


Fig. 14

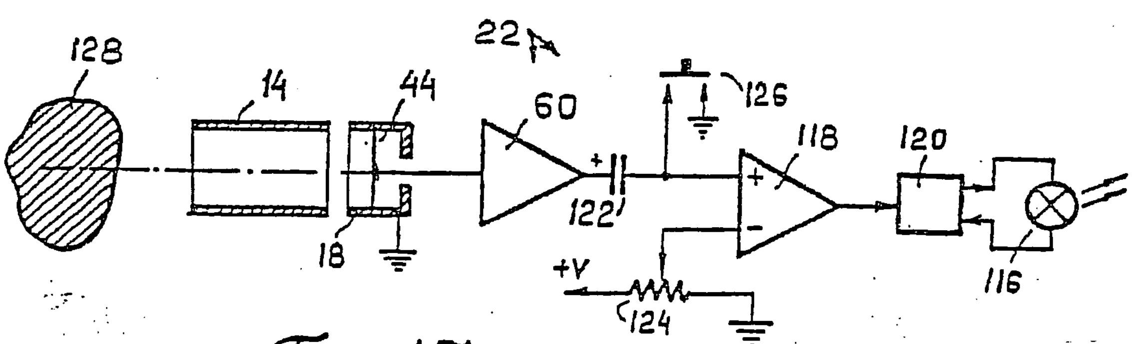


Fig. 15

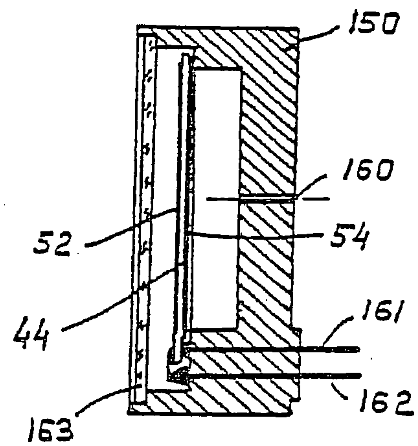


Fig. 16

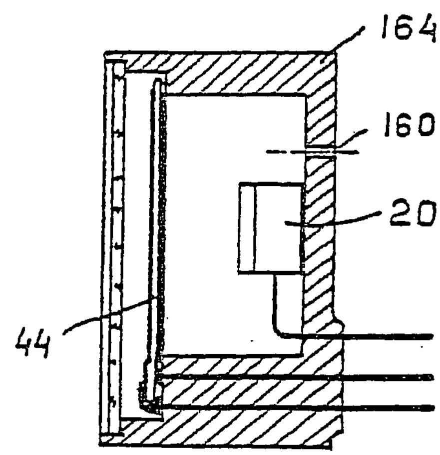


Fig. 17

INTERNATIONAL SEARCH REPORT

International Application No PCT/US86/00782

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC (4): G01K 7/02,04; G01J 5/12; A61B 5/00

U.S. CL. 364/557,571; 128/736; 136/213; 250/338; 374/2,133

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	128/736; 356/43; 374/1,2,104,121,128,130,131,132, 133,179; 136/213,214; 364/557,571; 250/338

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
A	US, A, 3,023,398, (Siegert), 27 February 1962.	
Y	US, A, 3,115,030, (Barnes Engineering Company), 24 December 1963, see column 3, lines 26 to 51.	10,14,23,24
A	US, A, 3,549,960, (Massachusetts Institute of Technology), 22 December 1970.	
A	US, A, 3,777,568, (Sensor, Inc.), 11 December 1973.	
A	US, A, 4,001,586, (Plessey Incorporated), 04 January 1977.	
Y	US, A, 4,005,605, (Mikron Instrument Company, Inc.), 01 February 1977, see column 3, lines 6 to 58 and column 4, line 5 to column 5, line 54.	1-3,7,8,10, 14,21-24,29-33

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
15 May 1986	02 JUN 1986
International Searching Authority [1]	Signature of Authorized Officer [10]
	Edward R. Cowman

International Application No. PCT/US86/00782

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

A	US, A, 4,147,562, (Honeywell, Inc.), 03 April 1979.	
Y	US, A, 4,379,971, (Statitrol, Inc.), 12 April 1983, see column 2, line 24 to line 34 and column 3, lines 7 to 15.	2,3,7,8,21, 22
Y,P	US, A, 4,527,896, (Mikron Instruments Company, Inc.), 09 July 1985, see column 3, line 30 to column 6, line 24.	17,18,33
A	"THIN FILM CUTS TIME OF DETECTOR RESPONSE " 16 June 1982, Electronics, pages 84 and 86.	

V.☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [10]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1.☐ Claim numbers ______, because they relate to subject matter [12] not required to be searched by this Authority, namely:

2.☐ Claim numbers ______, because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [13], specifically:

VI.☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [11]

This International Searching Authority found multiple inventions in this international application as follows:

1.☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2.☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3.☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4.☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.

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